Here's Proof . . .

that low Water/Cement ratios and adequate curing produce stronger concrete

DESPITE THE UNTOLD thousands of words that have been spoken and written on the subject, too many people in the concrete construction field are still unaware of the critical relationships between the water content of plastic concrete, the availability of moisture during curing, and the compressive strength of the resulting hardened concrete. The doubters and the uninformed may be impressed a little by the dramatic and conclusive proof provided by the simple test demonstration pictured here.

The test was performed in Dayton, Ohio, during a recent short course cosponsored by the Ohio Ready Mixed Concrete Association and the University of Dayton. Don E. Hoeffel, Portland Cement Association engineer from Cincinnati, conducted the demonstration which was originally developed by James W. McKnight, a Pittsburgh PCA engineer.

Four small test beams made by Bowser-Morner Testing Laboratories, Dayton, were broken. Hilltop Building Materials, Inc., Cincinnati, built the apparatus used to suspend the beams and the load. As the pictures show, the beams were subjected to bending stresses by the application of loads at mid-span. Concrete bricks weighing about five pounds each were placed on the loading platform until each beam broke as a result of the bending stresses.

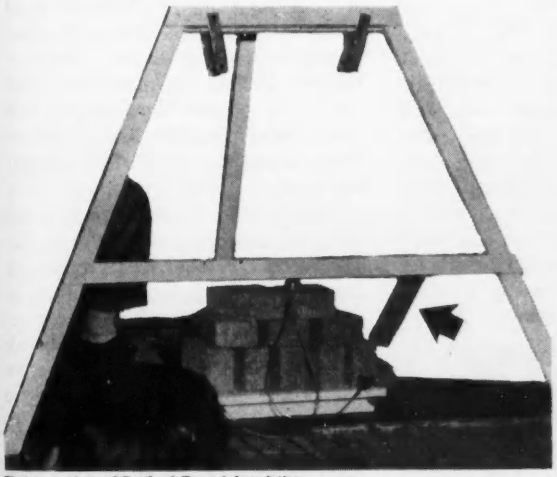
Two of the beams were made with a high water-cement ratio of 8 gallons of water per sack of cement (much too high to result in strong concrete). One was allowed to cure in open air and the other was kept moist for the first 24 hours. The remaining two beams were made with a water-cement ratio of 5 gallons per sack and cured similarly. The aggregate used was natural sand. Coarse aggregate was excluded. The beams had cured about 74 hours when they were tested.

In the demonstration at Dayton the dry-cured beam, made with concrete having a water-cement ratio of 8 gallons per sack, broke when 10 bricks (total weight about 50 pounds) had been placed on the loading platform. The moist-cured beam with the same water-cement ratio broke under a load of 15 bricks, indicating a 50 per cent increase in flexural strength as a result of better curing.

The dry-cured beam made with 5 gallons of mixing water per sack of cement broke under a load of 17 bricks, an increase of 70 per cent in strength over the first high-water-cement ratio specimen. The last beam broken was the moist-cured beam made with the 5-gallon mix. It broke when loaded with 26 bricks, again scoring a 50 per cent improvement over the equivalent mix dry-cured, 70 per cent over the moist-cured wet mix, and almost 170 per cent over the dry-cured wet mix.

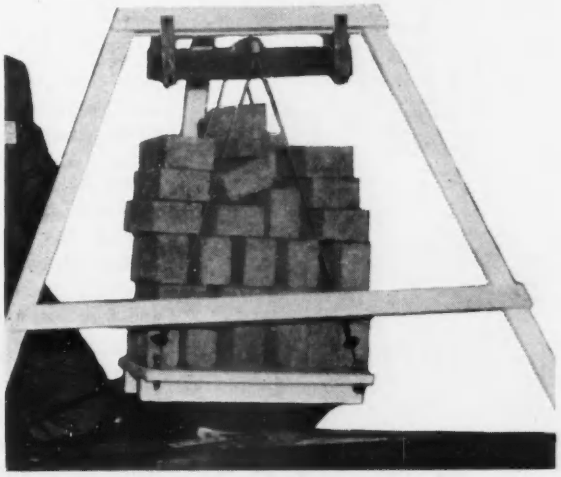
We've known for the past 35 years that the strongest concretes are those that attain plastic consistency with the lowest water-cement ratios. For an even longer period we've known that concrete will not develop its full potential strength if it is dried out too soon.

Both these statements are fully confirmed by the simple beam demonstration pictured here. The two principles are probably the most important ones in the entire technology of concrete. END

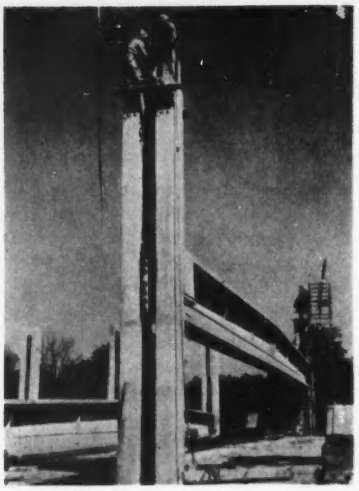


Photos courtesy of Portland Cement Association

Ten 5-pound bricks marked the end of the line for the dry-cured beam made with excessively wet concrete. The beam had just broken, and the pieces were still falling (arrow points to one of the pieces), when this picture was snapped.



Here the beam that was given a chance to cure, and that was made of concrete having a proper water/cement ratio, is shown just before it snapped under the weight of 26 bricks. The beams consisted of exactly the same materials.



This view, which also appears on the cover of this issue, shows the site where seven 138-foot prestressed beams were used in the auditorium at Parkview High School, Springfield, Missouri. Beams were cast at ground level, post-tensioned and then jacked up the side columns.

Let's take a look at . . .

PRESTRESSED CONCRETE

- **what it is**
- **how it works**
- **some problems**
- **the outlook**

This is concrete? A secretary at the Skokie Laboratories of the Portland Cement Association demonstrates the remarkable strength and resilience of a prestresed concrete plank.

THE NOVELTY OF PRESTRESSED concrete has largely been dispelled by this time. Mere employment of the process is no longer news. Progressive contractors, engineers and architects have blazed the trail and their more conservative colleagues have fallen in line.

When confronted with a new building technique, the accepted procedure seems to be: (1) test its practicality; and (2) perfect and extend the technique if it turns out to be sound enough to stand up under the rigors of field service.

Like airplanes, steam heating and sweater girls, which we like to think of as strictly products of American know-how, prestressed concrete is more universal in origin and early development than is sometimes conceded. A German, Doehring, conceived and patented the idea in 1888; a Frenchman, Freyssinet, was the first to make the idea practical; and today builders all over the world are wholeheartedly seeking ways to improve and widen its application.

A TWO-WAY STRETCH

But just what is the idea? Briefly, it is a method by which more effective use is made of the concrete in reinforced concrete. Let's look at three hypothetical beams to understand some of the general principles that govern the action of concrete members under loads.

Unreinforced. In the accompanying drawing, Beam 1 represents a concrete girder without reinforcement. If we assume an imposed load, the beam will tend to deflect downward. The interior forces set up by this action are of two natures: compressive and tensile. Concrete along the top of the beam is "squeezed" by compressive force; concrete along the bottom is "stretched" by a force referred to as tensile.

It must be kept in mind that while the compressive strength of concrete is quite high, up to a maximum of 18,000 psi, its tensile strength is low, usually somewhere in the neighborhood of 550 psi. In the unreinforced beam, the bottom edge would crack soon after any appreciable load had been applied; it would be literally torn apart.

Reinforced. Reinforcement is placed in concrete to absorb these tensile forces. Because these forces are concentrated in the bottom portion of members, the steel is placed there (see Beam 3). Unfortunately, considerable stress is placed on the concrete before the tensile forces are transferred to the steel. This causes the concrete to crack under loading even though it is reinforced. As a matter of fact, only one-third the concrete in a rectangular girder with conventional reinforcement (the top part that is in compression) is assumed to carry stress. It is

assumed that the bottom two-thirds will crack under load, and therefore will not contribute to the beam's structural strength.

No appreciable gain in tensile force resistance is achieved with concretes which have very high compressive strengths (say, over 8,000 psi). Use of high-strength steel, rather than mild steel, would only postpone the transference of tensile forces from the concrete to the reinforcing bars. If anything, this would increase the tendency of the concrete to crack under load.

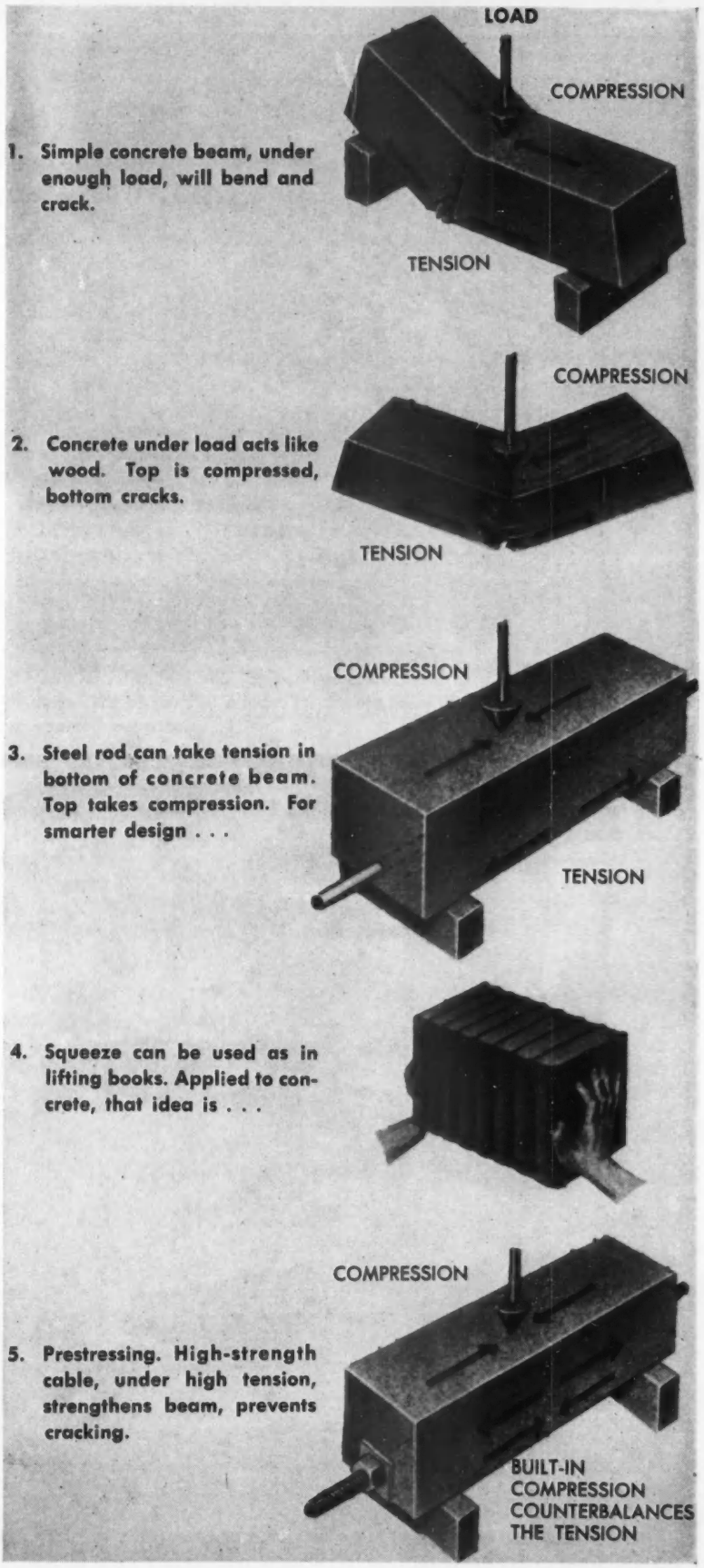
These facts, coupled with the stringent building codes prevalent in the United States, usually render ordinary reinforced concrete impractical[1] for frames of buildings that are over 25 to 30 stories, or that call for very wide bays. Beams for such structures would have very large cross sections and would be extremely heavy. These limiting factors affect the use of concrete in building frames, bridge girders, roof and floor panels, and almost every load-bearing application.

Research devoted to these problems has resulted in the evolvement of design and construction techniques that render ordinary reinforced concrete practical and competitive for a wide range of applications. Girder shapes have been developed to make better use of the materials employed, and considerable work has been done on the quality, placement and size of reinforcement. In some cases, extra large rebars, over 2 inches in diameter, have produced excellent results, especially in bridges. Recently, however, the Bureau of Standards announced that tests they have conducted indicate that in most construction, use of a number of small rebars results in less cracking than fewer bars of greater diameter.[2]

Prestressed. These improvements, despite their importance and value, minimize rather than eliminate the shortcomings. An entirely fresh approach to the problem was needed to take a real stride forward. Prestressed concrete has provided that fresh approach. Indeed, in several ways it has already proved to be superior to ordinary reinforced concrete in many building fields.

[1]Ultimate load design has changed this picture somewhat. For example, a 40-story apartment building under construction in Chicago will have a reinforced concrete frame.

[2]See CONCRETE CONSTRUCTION, October 1956, page 10.



1. **Simple concrete beam, under enough load, will bend and crack.**

2. **Concrete under load acts like wood. Top is compressed, bottom cracks.**

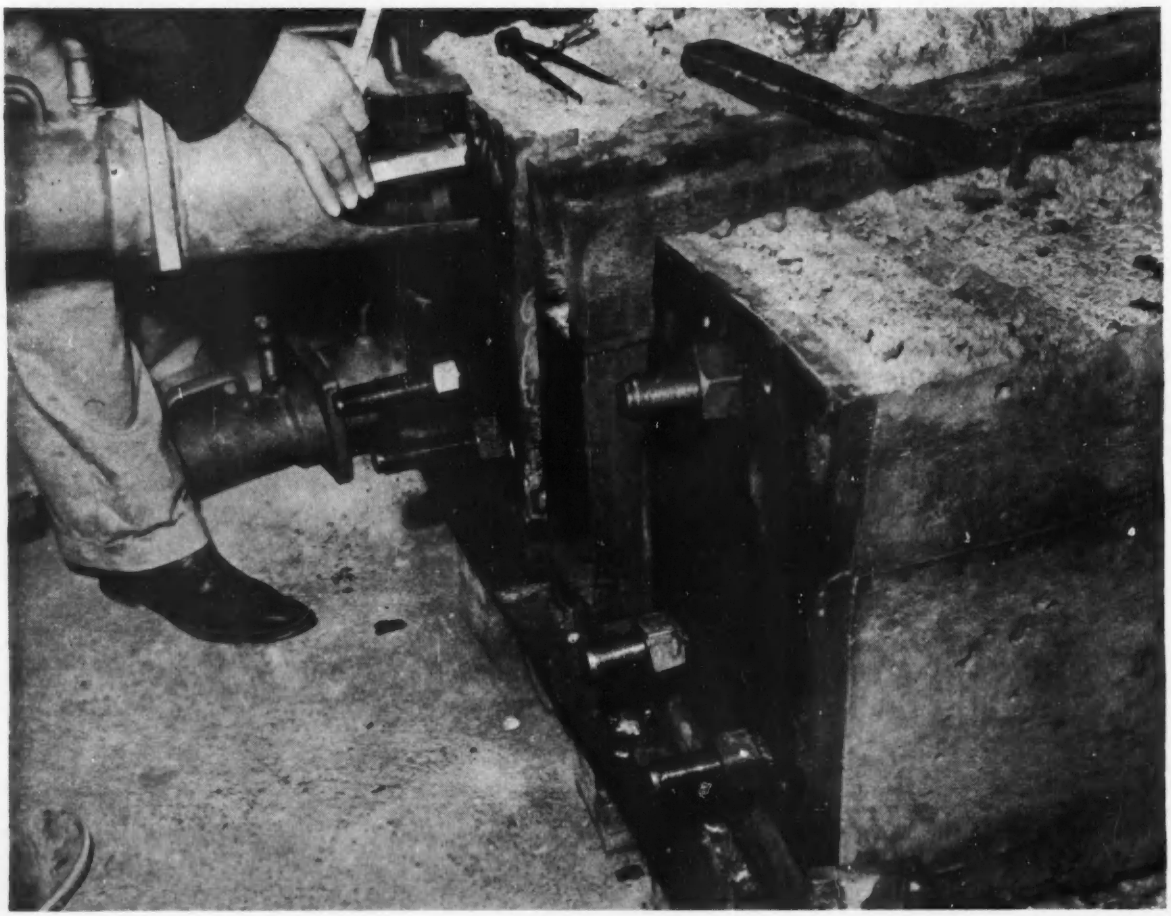
3. **Steel rod can take tension in bottom of concrete beam. Top takes compression. For smarter design . . .**

4. **Squeeze can be used as in lifting books. Applied to concrete, that idea is . . .**

5. **Prestressing. High-strength cable, under high tension, strengthens beam, prevents cracking.**

LEFT: Extensive use of prestressed members was made in the Pryor (Oklahoma) High School gymnasium. Four prestressed 100-foot girders support the roof channels and eight 35-foot prestressed beams support the bleacher seats.

BELOW: Fifty beams were required for the Endicott Street Bridge, Danvers, Massachusetts, the first prestressed bridge in New England. In the background, the studs of the two lower strands have been pulled and the nuts run up. The jack is attached to the draped strand. Note that the top of the end plate is bent slightly inward; this brings the bearing face of the stud exactly perpendicular to the axis of the draped strand.

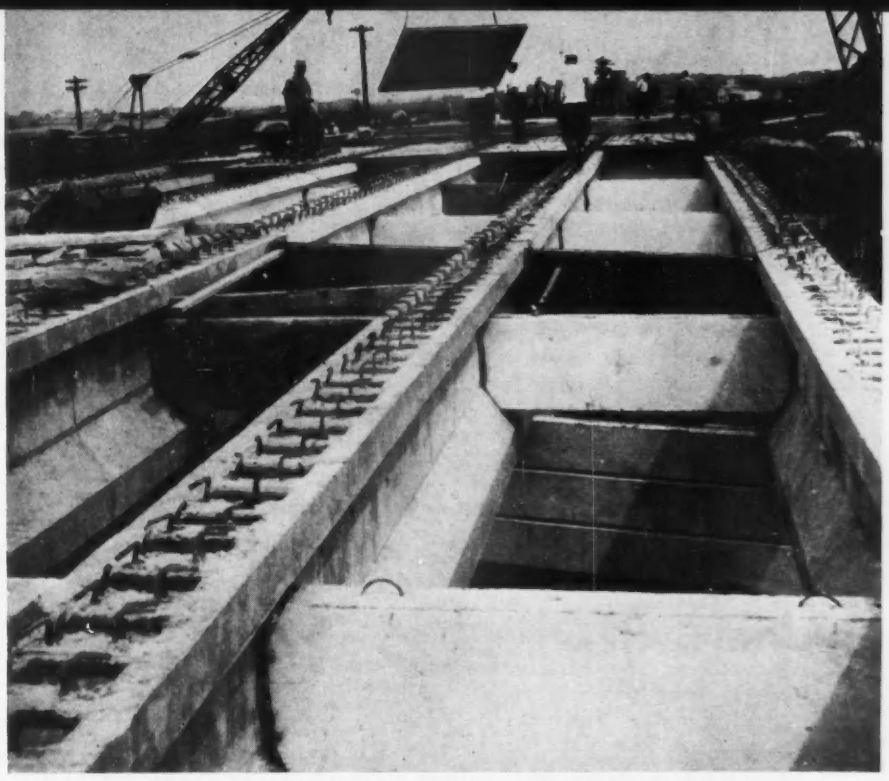


To understand the technique we can start by breaking down the word itself: pre-stressed. Reduced to its simplest terms, that is exactly the reasoning behind the new procedure; stress is applied to the concrete *before* load is applied.

This is accomplished by stretching the reinforcement, usually by hydraulic jacks. As a result, it ceases to act as reinforcement at normal loads and becomes merely an agent to apply a compressive force at the ends of the member. The same result could be achieved by a giant clamp.

Under overloads severe enough to stretch the cables, some of the characteristic properties of ordinary reinforcement are assumed. In order to take fullest advantage of the cables if overloading should occur, it is desirable to have them concentrated near the bottom of the girder, because this is where the greatest tensile stresses build up.

To oversimplify, we might say that the squeezing effect achieved by prestressing a beam causes the center to bend upward—just the opposite reaction from loading. Then, when a load is applied, as in Beam 5, the beam returns to a normal straight line. In this way, prestressing anticipates the deflection of a concrete member that will result from loading and compensates for it by setting up forces within the member that are directly opposite. One force thus cancels out the other.



Beverly Road Bridge, near Elgin, Illinois, was built as a test. As a result of the findings, 225 of the 285 bridges on the Northern Illinois Toll Route are to be of prestressed concrete.

ADVANTAGES

Prestressed concrete is crackless. Even under appreciable overloads, the concrete in a prestressed member is held under compression by the squeezing effect of the stretched cables. Even when cracks do appear, after a load several times the design load has been applied, they will disappear when the overload is removed, unless the cables have been stretched beyond the point from which they can snap back to their former length. That critical stress is called the cable's yield point.

This brings us to another advantage of prestressed units: their ability to recover after severe overloading. Under equal loads, a prestressed beam will deflect no more (usually somewhat less) than an ordinary reinforced beam designed for the same duty. After the load is removed, the prestressed unit returns much more nearly to its original shape. Since prestressed members can stand greater overloads than ordinary reinforced beams, they develop much more severe deflections before failure takes place.

BEFORE OR AFTER?

Two construction procedures with regard to time of stressing are possible in prestressed work: pretensioning and post-tensioning. In pretensioned work, the cables are stretched before the concrete is cast; in post-tensioned units, cables are stretched after the concrete has hardened.

The tensile force of the cables is transferred to the concrete by bond in pretensioned concrete. When cables are stretched, their diameter is decreased in direct proportion to the amount they are lengthened. Cables tend to snap back to their former length when released, but if encased in hardened concrete they are rigidly restrained. This struggle between the cables, which attempt to return to their original shape and the concrete, which holds them at their extended length and reduced cross-section, sets up the compressive force.

In post-tensioned work, force is transferred to the concrete by attaching plates to the ends of the cables. This sets up a squeezing action similar to that which occurs when you hold a number of books, without a bottom support, by simply pressing with your palms on the two end volumes.

Comparing the two approaches, it can be seen that post-tensioning work requires end anchorages to maintain cable tension. Considerable work has been done in developing simplified and low-cost devices, but these extra accessories do increase expenses in post-tensioned work.

Often, however, when very large girders are to be job-cast because of transportation difficulties, post-tensioning is the only solution. Also, in post-tensioning, there is an advantage in the ease with which cables may be draped.

Both the compressive and the tensile forces in a beam supported at each end vary considerably along its length. They are least intense at the ends and increase to a maximum at the center of the beam. Due to this characteristic, most efficient use is made of the prestressing cables if they are draped in a catenary curve rather than merely stretched straight.

As can be readily imagined, complications are in store for anyone planning to deflect cables and also tension them before the concrete has been cast. Some methods have been evolved, though, that permit one to have some cake and eat it, too.

One method employs inverted-U positioners of varying height that hold

the cables to a curve. Positioners are bolted to the base of the casting bed until after the concrete has hardened. Another method uses a yoke-like device from which bars extend downward into the form to hold the prestressing cables in an approximate arc. However, both of these methods retain one of the disadvantages of post-tensioned work: they require that high-strength accessories be incorporated in each unit fabricated.

GETTING INTO FOCUS

Several facts are evident from even such a cursory look at the prestressing concept and its application as this. For one thing, it is no longer merely an idea or a novelty; it has become an important reality. Prestressing has been and will continue to be a subject of conjecture, experimentation and development, but it is already a widely used construction technique.

We needed experience to bring into focus the problems that must be solved to extend and improve the application of prestressed concrete. Builders all over the world are making important contributions, and the whole pace of the development is today almost jet propelled. But even apart from the apathy and resistance with which most new radical design concepts are greeted, prestress has a few problems all its own. One of the most difficult is the very high capital investment necessary to manufacture prestressed units. Creep in concrete and cables poses some difficulties, and much remains to be learned about variable bond and the effect of volume changes in concrete.

That prestressing is making phenomenal progress despite these problems is evident even in the daily newspapers. Not long ago papers all over the country heralded the opening of the longest bridge in the world—the Lake Pontchartrain Causeway. Prestressed piles and deck units were credited with a sizeable saving in both time and money.

Of course, in many categories of construction there is still little use being made of prestressed units. A notable example is multi-story building construction. But with the increasing acceptance of prestressed concrete this promising and versatile material seems almost certain to gain wide acceptance for virtually every type of construction work. It is moving rapidly into the forefront of our major materials of construction. END

WHAT'S THE SCORE ON PRESTRESSING?

THE ADVANTAGES

1. **Elimination of cracking.**
2. **Reduced cross-section of members.**
3. **Reduced weight of members.**
4. **Less concrete needed.**
5. **Longer spans possible.**
6. **Greater recovery after overloads.**

THE DISADVANTAGES

1. **Highest quality materials required.**
2. **Closer control needed.**
3. **Skilled workmen required.**
4. **Greater capital investment for prestressing equipment.**
5. **High cost of end anchorage units (in post-tensioned work).**

Some Common Terms in Prestressed Concrete

BED: the form and abutments that are used to cast prestressed members. Forms must be rugged to withstand many reuses. Abutments through which the prestressing cables pass and against which they bear until the concrete unit has hardened, have to be able to withstand the tremendous pressures exerted by the prestressing jacks.

CABLE: a composite of several extra high-strength wires.

CATENARY EFFECT: both tensile and compressive forces are least severe at the ends of a beam and most severe in the middle. In view of this, full advantage is taken of prestressing cables only when they are draped in a catenary curve (the curve a flexible piece of rope would assume when held horizontally at both ends). This is referred to as the catenary effect.

COMPRESSIVE STRENGTH: resistance to squeezing forces.

CREEP: the tendency of elastic materials, e.g., concrete and steel, to "give" or "relax" slightly when under continued stress.

DEAD LOAD: weight that a member must be expected to support at all times, e.g., its own weight and that of roof topping, walls, etc.

DESIGN LOAD: weight which unit was planned to support.

END ANCHORAGE: device at each end of a prestressed unit to hold cables at proper tension.

LIVE LOAD: weight of a temporary nature that members are expected to support, e.g., snow, wind, people and vehicles.

RECOVERY: ability of a member to return to its original shape after it has been deflected.

SERVICE LOAD: dead load plus live load.

STRAND: a factory-produced unit of helically-wound, small-diameter wires.

TENSILE STRENGTH: resistance to stretching forces.

ULTIMATE LOAD: least weight under which a member will fail.

YIELD POINT: smallest amount of stretching from which a cable will not be able to snap back to approximately its original length.

Photo courtesy of Stow Manufacturing Company

This special underslung screed has its vibrating assembly and end rollers simply bolted to the timber beam. They can be readily removed and remounted on other beams. The screed shown here strikes off and shapes the concrete surface as it is pulled along.

For quality concrete surfaces on that next roadway, bridge deck, or floor job, consider . . .

The Vibrating Screed

THE VIBRATING SCREED is being used more and more by contractors for striking off concrete slabs on roadways, bridge decks and floors. It permits the placing of even 1- to 2-inch slump concrete, and it strikes off this relatively dry material smoothly and quickly.

A vibrating screed consists of a beam with a vibrating unit, which is generally mounted in the center of the beam, and a pair of end roller assemblies. The vibration is transmitted through the length of the beam directly to the concrete. There is no transverse movement of the beam. The screed is merely drawn directly forward with the end rollers riding on the forms or rails.

Large concrete highway paving machines cannot be used economically on small sections of concrete highways or on bridge decks. For this reason these slabs are often hand finished using a soupy mix, which results in poor concrete surfaces, high maintenance costs and disgruntled highway engineers. Now vibrating screeds are solving this problem. On floor jobs, too, the vibrating screed can do a faster and better job than hand methods.

Because it does not have transverse movement, it is possible to build any reasonable cross section into the bottom of a vibrating screed beam. This means that any desired crown or slope can be obtained without getting the surface distortion caused by the sawing action of hand screeds. Usually, the resulting surface is smooth enough so that very little, if any, bull-floating is required.

Vibrating screeds not only strike off the surface and shape it as they are pulled along, but they vibrate the concrete at the same time. This means that all of the advantages of vibration are obtained, such as greater density and homogenity in the concrete. Also, because of the vibration, a much stiffer mix (even 1-inch slump concrete) can be struck off than is usually poured when hand methods are used. A stiff mix, of course, makes a much stronger concrete.

Most vibrating screeds have rubber vibration dampeners between the end roller assemblies and the beam. This, plus the fact that the beam is supported so that it rides about ⅛ of an

inch above the forms, prevents the vibration from being transmitted to the forms. Whether the screed is electric or gas operated, a method is provided to quickly stop or start the screed's vibration. This is important to prevent over-vibration when the screed is standing still. Also, a means is provided to make it simple to raise the beam up slightly off the surface in order to roll the screed back for a second pass where necessary.

Not only do vibrating screeds give the public a much better riding surface, but they save the contractor a considerable amount of money because of the speed at which they operate. Experience has shown that with the same crew, a contractor, even on concrete bridge decks, can often cut his production time almost in half. Naturally, vibrating screeds are much less fatiguing to operate than hand strike-off machines.

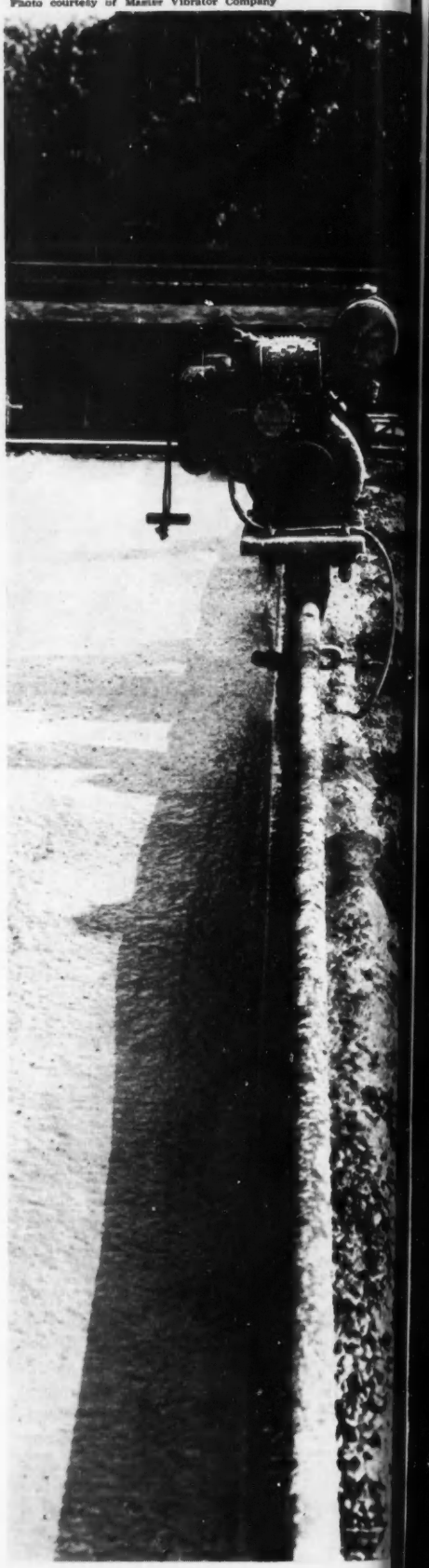
For sections of highways, the steel forms should be put in securely to support the weight of the screed. In most cases, the top of the form is on the same level as the concrete surface so that a straight beam can be used with a crown in it if desired.

Concrete is poured from 15 to 20 feet ahead of the screed and raked to the approximate height of the forms. Then the vibration is started up on the screed, which is pulled along by two to four men, depending upon the length of the span and the stiffness of the concrete. Sometimes the concrete may not be up to the level of the forms, which leaves bare spots; when this happens the screed beam can be raised up off the concrete surface and rolled back for a second pass. It may be found that intermediate vibration speeds are more desirable for particular mixes or different length beams. Generally, the stiffer the mix and the longer the beam, the greater the vibration speed required. Also, the speed at which the screed is pulled along will affect the results. After only a few minutes of operation, a satisfactory vibration speed and pulling speed can be found. After screeding, the surface is ready for broom or burlap roughening.

On concrete bridge decks, the procedure is about the same as for highways. Vibrating screeds with spans up to 30 feet have been used successfully on bridge decks on the New Jersey, New York, Massachusetts, and Ohio Turnpikes, as well as many others.

On these decks, the exact height of the "I" beam rails and spacing is important to maintain the proper finished grade and specified thickness of the slab. These rails are often located above the surface of the concrete, allowing the concrete to be poured underneath them. In this case, underslung type beam construction can be used. The contractor can make his own beam or give the screed manufacturer a sketch showing the exact relationships between the surface to be screeded and the rails that the rollers will ride on.

Photo courtesy of Master Vibrator Company



This 36-foot vibratory finishing screed is being used on a bridge deck on a new turnpike. With one pass of the screed, the contractor strikes off and compacts the concrete and produces a better slab.

Some states specify that bridge decks should be single surface decks, while others specify a riding surface deck. On a riding surface deck, the first thickness is poured and then a topping of about two inches of concrete is poured over it. It is advisable to finish the lower thickness of a riding surface deck with a vibrating screed, for if it is not flat and smooth, the top surface will not be flat either.

The procedure for screeding concrete floors is similar to that on roadways. It is advisable where possible to engineer the concrete slabs specifically for vibrating screeds. Forms can be laid out in lanes of equal width so that the same length screed can be used on all lanes. Also, it should be planned so that any vertical columns will be next to a form so that the screed can easily be lifted around the column. Steel forms should be put in securely to support the weight of the screed.

To summarize, the following are the important advantages to using vibrating screeds:

► They encourage the use of low slump concrete, resulting in stronger slabs and better wearing surfaces;

► They reduce, and sometimes eliminate, the necessity of bull floating;

► They make it possible to shape the surface at the same time it is struck off;

► They increase the density of the concrete, resulting in a superior wearing surface;

► They make it possible to start trowelling sooner, since the drier mixes set up more quickly. END